If the observations of meteor-train drifts were reported to one observer or to a specially appointed committee, whether the observations are made casually or from the result of a well organized plan, it would seem probable that in a few years enough drifts could be recorded to bring to light much concerning the movement of the higher atmosphere.

In closing I wish to thank the editorial staff for kindly furnishing me with some valuable data on meteor trains found in the files of the MONTHLY WEATHER REVIEW, and also Miss F. Harpham, of the astronomical computing staff at Columbia University, for assistance rendered on several occasions.

SPECTRAL FORMS IN MIST AND RAIN.

Talla Water is a lake from which Edinburgh derives its water. According to Dr. Hugh Robert Mill, director of the British rainfall organization (see British Rainfall, 1903, p. 49) "Talla is a classic land of rain". Sir Archibald Gilkie refers to it in his Scottish Reminiscences, thus:

The Talla Valley is narrow and deep, the hills rising steeply from 1,000 to 1,400 feet above the flat alluvial trough at the bottom, which is about 900 feet above the sea. In the days of which I am speaking it was a lonely, sequestered glen, silent save for the bleat of the sheep or the bark of the dogs. In wet weather the wind drove up or down the defile, separating the rain into long vertical shafts, which chased each other like pale spectres. In the narrower tributary gorge of the Games-hope these ghost-like forms are even more marked; hence they are known in the district as the "white men of Games-hope".

STUDIES OF FROST AND ICE CRYSTALS.

By WILSON A. BENTLEY. Dated Jericho, Vt., May 28, 1906. Revised July, 1907.

(Continued from August Review.)

The extreme difficulty of detaching and securing entire specimens of this type of frost for our purposes has prevented our photographing more than a very few of them. Those that the author succeeded with were, with but one exception, formed around frost nuclei upon windowpanes. For examples of this type of hoarfrost as formed in the open air, see No. 27 A. For additional mention of this type as found indoors on windowpanes, see No. 154 A, type WMD, in section 34, and Nos. 154 B and 161, type WSE, in section 35.

It is of much interest to find within this type of crystal, as within the other similar types heretofore mentioned, systems of air tubes and air inclusions. With the other points of similarity between them this serves to establish still more clearly the probability of the common origin of such air inclusions within both snow and frost crystals.

(17) HTG. Tabular snow crystals with hoarfrost additions.

A most important phase touching both snow and frost study is that relating to changes in habits of growth that may be induced by changes in environment. Very interesting opportunities are occasionally furnished for studying effects of this character, for on rare occasions snow crystals fall at nightfall, and hoarfrost crystal additions form in graft-like fashion upon them before they are modified by evaporation or by melting. This enables the student of crystallography to observe whether such hoarfrost additions as form on and grow outward from such fallen snow crystals conform to their own natural habits of growth, or to those of the fallen snow crystals. It would appear, from what the writer has learned from such few cases as have come under his own observation, that the hoarfrost additions, or grafts, grow and conform to hoarfrost types, rather than to snow-crystal types. Our photographs Nos. 96, 97, 98, and 99 show hoarfrost grafts or additions attached to freshly fallen snow crystals. It is remarkable that all the snow crystals of this series, as well as all the others having hoarfrost additions that have come under the writer's observation, are of a similar branch-like character.

It will be noted by consulting the photographs that in all but one the hoarfrost additions grew in a broad, solid, tabular fashion, in marked contrast to that of the frail, branch-like, snow crystals from which they started. Only in one case, that of No. 99 (which it will be noted portrays but a single segment, or branch-like ray added to the snow crystal), does the hoarfrost addition show a general near resemblance to the snow crystal from which it grew.

COLUMNAR HOARFROST.

Under this title are grouped all hoarfrost crystals that assume the forms of solid or hollow hexagonal columns, hollow hexagonal funnels, combinations of these to form compound crystals, and longitudinally bisected segments of columns and funnels.

(18) Type HCA. Columnar hoarfrost. Hollow columns.

Crystals of this type form in the shape of hollow hexagonal cylinder-like columns. This type of the column is commonly less slender and less elongated in the direction of its main axis than are those of the solid and of the solid fibrous types of the column to be described later. They vary in size from perhaps one-sixteenth to one-sixth of an inch in longer diameter. Many of them taper somewhat toward their bases. When formed in the open, they are essentially mild-weather types. They are most common to early autumn and late spring, and the hoarfrost that collects upon the plants and grasses during the so-called destructive frosts at those dates is almost invariably of this type. Hoarfrost deposits of this character form in the open during calm, clear nights when the surface air temperatures range from 56° to 40° at nightfall, and from 32° to 25° during the latter part of the night or early morning. Sometimes the cold becomes most intense and frost forms most rapidly in the early morning hours between daybreak and sunrise. Crystals of this HCA type rarely or never appear in relatively large numbers in the open simultaneously and associated with tabular hoarfrost crystals. During nights when tabular hoarfrost crystals predominate, this type, HCA, forms in general only on the bare ground and on the under sides of such objects as wood, leaves, straw, etc., that lie directly upon the bare earth, and not insulated from it.

In winter time the shorter and more perfect specimens of this type of frost are of relatively rare occurrence upon the shrubs, grasses, etc., in the open; but they frequently form in winter within relatively warm and inclosed, or partly inclosed, air chambers, as on the sides and roofs of cavities in the snow extending down to moist soil or water, on the under sides of water-trough covers, or of objects such as wood, embedded in the snow. In such confined situations they often grow for a long period of time, and hence attain much greater dimensions than in the open. Many of the individual crystals of this type exhibit but little variety, and a few specimens serve to carry an idea of all. It sometimes happens that they combine with hollow funnel-shaped crystals; funnel-shaped additions grow outward from the apices of the hollow columns and form compound crystals, presumably as a result of a change in atmospheric conditions. (See type HCE.)

Our photographs, Nos. 36 A, 36 B, 36 C, 36 D, and 36 E, quite correctly portray the aspect and general forms of such types of columnar hoarfrost crystals. Nos. 36 A and 36 E show them as collected in autumn and spring during destructive frosts upon grass blades and strawberry-plant leaves, respectively. Nos. 36 B and 36 C show these forms more highly magnified. No. 36 D pictures them as crystallized upon a cedar post.

(19) Type HCB. Columnar hoarfrost. Solid columns.

Hoarfrost crystals of this type grow in the form of the solid column. There are three varieties of the solid column. Some grow in the form of long, slender icy needles, others in a quasi fibroid form. One variety grows in the form of relatively short hexagonal columns, which greatly resemble crystals of type HCA, and in fact differ from them only in this, that each of the six respective walls or sides of the column possesses so great a thickness that they almost or quite meet at the center of the main axis, and hence leave no space, or but a very small cavity, between the several surrounding walls of the hexagonal column (see photograph No. 36 A). The fibroid and the needle-shaped crystals are peculiarly extreme cold, zero-weather types. They most frequently form and lie in a horizontal manner directly upon the bare surface of pond and river ice, or directly upon bare compacted soil. They rarely or never grow upward from soil or ice, as do the branching tabular frost crystals (types HTD and HTE) so often found associated upon the ice with them. Walls abounding in cracks and small apertures thru which strong cold and moist air currents circulate are often coated with a subcrystalline granulo-fibroid variety of solid columnar hoarfrost. Crystals of a similar character, and also long needle-shaped ones, sometimes form upon the snow and other objects that inclose or closely adjoin open flowing springs of water. As previously noted, the clouds enshrouding mountain summits often deposit a portion of their moisture in the form of cloud frost crystals of a form and character similar to those just described. Mountain climbers assert that crystals of this character sometimes grow to an astonishing size in such high situations under the influence of a steady stream of cloudy air. Needle-like and fibroid crystals, as commonly formed on ice and soil, vary in length from a fraction of an inch to as much as one or two inches. It is of interest to note that each of the several varieties of solid columnar hoarfrost crystals is represented by corresponding prototypes among the snow crystals. Our photograph, No. 27 C, shows the form and aspect of solid columnar needle-shaped hoarfrost crystals as formed on bare ice, and No. 27 D pictures them as they appear collected upon the bare soil. The columnar crystals are identically alike whether formed on bare ice or on bare soil. No. 35 A shows typical specimens such as crystallize on plants and grasses, boards, and other objects.

(20) Type HCC. Columnar hoarfrost. Hollow funnels.

These singular crystals of frost form in the shape of hollow hexagonal funnels. They occur both as distinct entities by themselves, and as attached to the apices of hollow columnar frost crystals of type HCA. They occur both during extreme cold and during relatively mild temperatures, but most frequently during moderate degrees of cold, and form in various situations, both in the open and within inclosed situations. They rarely grow to a very large size. The degree or angle at which the sides of the funnels flare outward from an imaginary central perpendicular axis varies in different crystals. In some rare cases, as in No. 116 for example, the walls of the funnel flare outward at an extreme, and almost perpendicular, angle, but more frequently the sides of the funnels flare outward at angles more nearly approximating 60°, as shown in photographs Nos. 37 and 225. Sometimes six segmentary points or rays are found attached to and growing upward from each of the six points or angles where the several sides of the funnel meet, in the manner shown in photographs Nos. 116 and 225. (No. 225, it should be noted, is a photograph of an artificial illustrative model.) These projecting points probably give us the clue to the manner in which this type of crystal grows. Many of them doubtless grow, after being fully organized, by first throwing outward and upward points or rays as in No. 116, and then follows a process of growth that accomplishes the filling in of the open side spaces lying between the several points. This alternate process of growth is repeated from time to time until completion. It is most strange, in view of the fact that columnar frost crystals form in great numbers, and under most varied conditions, environments, etc., that tabular outgrowths do not form and grow outward from the sides or ends of such columns on a perpendicular to their main axes, in the same manner as do the tabular additions that so frequently form upon columnar snow crystals, resulting in doublets, or the cuff-button type.

The additions that grow outward from the apices or ends of columnar frost crystals, and that go to form the funnel additions thereto, evidently correspond most closely to the snow crystal doublet additions just described, yet for some inexplicable reason practically all the growth of this character added to the columnar frost crystals is grafted on, and grows outward from such columns, at angles of about 60°, and forms funnel-like additions, instead of growing at angles of 90° to form tabular plate-like additions, such as the snow doublets possess.

(21) Type HCD. Columnar hoarfrost. Longitudinal segments.

These queer types of frost crystals form in the shape of longitudinally bisected segments of hollow hexagonal and hollow funnel-like crystals. They seem to form largely or invariably within confined situations, as within hollow trees or cavities therein, between layers of ice, on the ceilings of barn cellars, and beneath blocks of wood, metal, etc., embedded in the snow. They usually assume a horizontal or oblique position upon the object upon which they form, and rarely or never grow outward perpendicularly to the face of such object. In some cases the apices of such crystals possess cap-like icy projections that extend outward normal to their facets.

(22) Type HCE. Hoarfrost. Compound crystals.

Compound hoarfrost crystals consist of two or more distinct types combined and united one to another. Crystals of this character are produced as a result of some change taking place in the rates and habits of growth which operates to produce crystals of a different type from that of the basal crystal upon which they graft themselves. Compound crystals form much more frequently in confined situations and within inclosed air spaces than in the open, yet one variety, a combination of column and funnel, sometimes forms occasionally in the open. They seem to be common to various temperatures.

Our photographs Nos. 162, 163, 201, 206, 207 A picture some very interesting specimens of compound crystals. In the case of Nos. 162 and 163 hollow hexagonal columns formed upon and around and grew from the angles of basal tabular crystals in a direction parallel to their faces. This is a somewhat rare combination.

Perhaps the most common type of compound crystal is formed in the very interesting manner shown in photograph No. 201, i. e., thru funnel growth forming and growing upward from the apices of hollow columnar crystals.

In the case of the variety of compound crystals shown in photograph No. 206, a perfectly solid and transparent short, square-ended, quasi-trigonal columnar crystal formed and grew upon and above a thick tabular crystal. Crystals of this gem-like character are sometimes, as in this case, perfectly limpid and free from internal markings due to air inclusions, and possess brilliant, clean-cut facets that flash and sparkle in true gem fashion.

In the case of No. 207 A, we see another variation in the form of the solid prismatic crystal as described above. In this case the crystal is viewed from the side. Its ends, instead of terminating in plain facets, as in No. 206, terminate in oblique facets. Unlike No. 206, it possesses interior lines and shadings, presumably due to included air. So far as observed, short, gem-like, frost crystals, resembling those just described, form only in inclosed situations wherein moisture gathers, as upon the under sides of blocks of wood embedded in the snow, in hollow trees, or cavities therein, and within other cavities similar to those wherein type HCD forms.

Occasionally crystals of frost that form upon the under sides of objects embedded in the snow assume very strange and rare forms indeed. Photograph No. 207 C portrays specimens of great rarity and interest. These are viewed endwise in the photograph. They grow upon cubical rather than hexagonal plans, assuming the form of the inverted cubical pyramid. They grow upward in such a manner that what should be the apex of the pyramid is below and supports them, while the base proper is above, and forms the summit. A most remarkable feature about them is the presence of shallow, four-sided cavities or depressions extending downward from their upper, basal portions. The outlines of these cavities may be plainly seen in the photograph.

This rare and strange form of hoarfrost crystal has no prototype among the snow and ice crystals, and only some of those that result from the evaporation and recrystallization of old snow beneath a hard snow crust, during intense and long-continued cold, at all resemble it. Crystals of snow-frost of this latter character will next be considered.

(23) Type HCF. Snow-frost crystals.

In addition to the various types of frost crystals previously described there are others that form within and beneath the surface of old snow. Frost crystals of this character draw their supplies of moisture largely from that which results from the partial evaporation or sublimation of snow crystals and of snow granules. Snow-frost crystals presumably form both on nuclei of their own making, and on the individual snow granules of which old snow is in part composed. They assume solid columnar and some other related forms. Some of them resemble cubes, and cubical pyramids. Many of them greatly resemble the short prismatic crystals of frost last described, type HCE. In many cases they are almost as broad as they are long. Such masses of metamorphosed snow are much heavier than new snow, and have a salt-like aspect and behavior, and melt very slowly. Photograph No. 207 B will serve to convey some idea of the general forms of such snow-frost crystals. As will be noted they closely resemble the one in photograph No. 207 A.

A very interesting account of this variety of snow frost will be found in an article by Mr. J. Wolley, M. A., in the Report of the British Association for 1858, part 2, pp. 40–41, reprinted in the MONTHLY WEATHER REVIEW for April, 1905, p. 158.

III.—WINDOW-FROST CRYSTALS IN GENERAL.

(24) Introduction.

Window-frost crystallizations are so instructive that they require especial mention in a chapter by themselves.

In view of the great beauty and variety of these fairy-like formations, and the ease with which they can be studied and photographed, it is surprising that so few of them have been photographed and published. We recall but one illustrated article treating of them, which was written by Mr. Babcock, of Wisconsin, and appeared in a recent number of the St. Nicholas Magazine.

(25) General conditions for formation.

Before proceeding to group and classify window-frost crystals, we will briefly state the general conditions under which they form, and what conditions or factors seem to determine their form and structure, together with some other facts and speculations of general interest. It may be well to state here also that the large feather-like and other crystals that so frequently form within a thin film of water, covering windowpanes within artificially heated rooms, are not frost crystals, but varieties of ice crystals, and as such receive mention later under the title "Window-ice crystals".

Window-frost crystals form under varying conditions of temperature, humidity, exposure, and environment. They freely form upon the windowpanes in both cold and warm rooms. True crystalline window frost forms only in a quiet, or relatively quiet, atmosphere, and commonly only when the outdoor temperature is several degrees below the freezing point of water, and four or more degrees lower than the temperature indoors.

In general true window-frost crystals form only when the humidity indoors is not excessive. When interior moisture exceeds a certain point (about 95 per cent relative humidity), a dew-like deposit of moisture, consisting of minute liquid water particles, forms upon the window glass and freezes in granular form thereon, so as to prevent the formation of true frost crystals. (See granular window frost, type WGK, sections 42, 43, 44.)

(26) Special manner of formation.

Window-frost crystals may be divided into two principal divisions: (1), those that form in minute striations or scratches in the glass, recurring time and again in the same position on the glass; (2), those that form outside and seemingly independent of such striations, and do not form repeatedly in the same position on the glass.

Doubtless in general, the nuclei of those varieties or types of window frost that form and grow without the striations in the glass, collect within minute indentations therein, or upon particles of foreign substances thereon, or form and attach themselves to the slightly thinner and consequently colder points upon its surface. Were it possible for conditions and the state of the surface of the glass to be such as would allow window-frost crystals to grow freely in all directions and in a perfectly natural manner, as do many of the snow crystals, they would doubtless grow and develop into exquisitely beautiful and symmetrical crystal structures. They would, indeed, exceed snow crystals in beauty and complexity of outline, tho of course not in beauty and complexity of interior. Even under the imperfect conditions, such as prevail upon ordinary windowpanes, many of them, as all know, develop into forms of great loveliness, and some of them even succeed in growing upon the glass in a very natural way, i. e., in the form of branching six-rayed hexagonal stars. Yet it is rarely the case, even when they succeed in growing in the manner last described, that they can grow in a perfect symmetrical manner, for even when crowding does not interfere with or prevent them from growing symmetrically, other factors generally do so. The inequalities in thickness, and the resultant variations in coldness of different portions of the glass, and the presence at some points and absence at others of aggregations of dust particles thereon, and the direction and force, as well as varying temperatures, etc., of the tiny air currents that flow over its surface, usually operate to favor and unduly stimulate the growth of certain portions of a given crystal, and to retard the growth of others. What part the dust particles play in forming centers for crystallic nucleation to commence upon is as yet problematical.

(27) Relation of crystals to foreign substances.

When the crystallization of a given salt or substance in solution is taking place, that salt or substance tends to exclude all foreign salts and substances from entering into the crystallic structures which it creates, and to produce chemically pure crystals. It is not clear to the writer how this well-known fact can be made to harmonize with the present belief that snow, frost, and ice crystals, as well as dew and raindrops, adopt and form only around dust particles, i. e., upon substances of an alien nature. The writer's own observations of window-frost crystallization lead him to the belief that window-frost crystals form with even greater freedom on newly cleaned window glass than they do on uncleaned, dust-covered panes, and he has no doubt but that they would form freely upon windowpanes rendered by chemical processes free from dust particles. The writer has frequently noted that the presence of excessive quantities of dust upon windowpanes tends to prevent the formation of the more beautiful of the frost crystallizations thereon.

Of course, in the case of the frost crystals, they must in many cases necessarily form, or at least rest upon, substances of a foreign nature, such as window glass, grass, plant leaves, etc. We may confidently assume, however, that in a majority of cases microscopic dew droplets collect and freeze upon the substances upon which hoarfrost crystallizes, prior to the formation of such frost crystals, and that these furnish tiny ice nuclei for the latter to form upon.

(28) Effect of temperature and humidity.

The temperature and humidity of the air, and especially the outdoor air temperature, exert a great influence upon, if, indeed, in many cases they do not actually determine, form, type, and structure of the window-frost crystals. Yet it would seem that other factors sometimes enter into the problem, because it often happens that two or more distinct types form and grow simultaneously upon a given windowpane. Doubtless, as Prof. J. P. Iddings suggests, form and structure depend largely upon their rates of growth, and the rapidity of the change of the temperature and humidity of the air. Certain types seem to be common to various diverse temperatures and humidities, for they freely form within both warm and cold rooms.

Some seem to form only within certain limited ranges of temperature and humidity, but others only at very low temperatures. In general the smaller and more solid types form most freely in a very cold atmosphere, and increase in number with a decrease in temperature. Singularly enough, certain branchy, open-structure types also form freely during intense cold, provided the humidity is considerable and moisture is freely supplied. By far the greater number of the more beautiful and interesting window-frost crystals form within cold, unheated rooms, and in temperatures ranging from 36° to 5° F. The great majority of those observed and photographed by the writer formed within such cold, unheated rooms. If care is taken to provide or select rooms varying greatly one from another as regards their temperatures and humidities, frost crystals can be observed and studied therein under almost as favorable and varied a range of conditions as within the laboratory itself. The writer has for many years conducted a series of observations under varied conditions such as just described. Three rooms were selected within which to observe window-frost crystallization. One of these possest a very cold, humid atmosphere, an open water tank with running water being therein, the second possest a very dry atmosphere, and the remaining one an atmosphere neither very dry nor very humid. Early in the winter of 1906-7, the Weather Bureau kindly loaned me a sling psychrometer to aid in my observations and to record the precise temperatures and humidities within these several rooms while particular types of frost were in process of formation. The results of my observations may possibly be of interest. Window frost formed upon the windowpanes within the driest of the three rooms upon 52 separate occasions, and upon the windowpanes within the other two rooms upon over 60 different dates; thus furnishing over 170 distinct opportunities for observing and studying window frost, and the temperatures and humidities prevailing while it was in process of formation.

It should be noted here that these observations, being conducted only within cold, unheated rooms, give complete data only as regards types of frost common to such cold rooms. This should be borne in mind when consulting Tables 1, 2, 3, giving the relative frequency of occurrence of the various types. These three tables show that in general the majority of the frost types were formed within atmospheres ranging in relative humidity from 55 to 70 per cent and in temperature from 36° to 5° F. (indoors). Within the coldest and most humid room, however, the majority of types formed when the relative humidities were higher and ranged from 74 to 86 per cent. Frost formed in a few cases in an atmosphere having relative humidity of but 47 per cent, while in others (within the coldest room) it formed when the relative humidity was as high as 92 per cent. It is surprising, indeed, as was found to be the case, that so many of the types of frost should form under such varying conditions and ranges of humidity and temperature. Among the facts of interest that we noted regarding the occurrence of the various frost types was this, that the types we have designated as WOH and

TABLE 1.—*Total number of occurrences of various types of window-frost crystals within the several cold, unheated rooms, in connection with various outdoor temperatures.*

Outdoor temperature.	WGK.	WLA.	WBB.	WFC.	WMD.	WSE.	WLF.	WCG.	WOH.	WTI.	WFJ.
° F.											
30	2	2	2	......	......	......	......	......	......	......	......
25	1	1	1	......	......	......	......	......	2	......	......
20	2	2	2	......	......	......	......	......	2	......	......
15	13	15	11	......	......	......	......	......	2	1	2
10	17	14	17	2	2	2	......	......	4	0	2
5	16	14	17	10	0	2	......	......	4	3	3
0	22	18	27	13	3	5	2	......	3	8	10
−5	13	14	10	9	2	4	3	......	1	3	3
−10	13	14	23	7	3	10	5	1	3	8	4
−15	6	6	13	10	7	14	5	2	0	7	1
−20	6	8	15	4	6	7	10	3	1	12	2
−25	5	0	9	3	5	0	9	6	0	8	0
Total ..	117	108	147	64	28	54	34	12	22	50	27

TABLE 2.—*Total number of occurrences of various types of window-frost crystals in cold, unheated rooms, in connection with various indoor temperatures.**

Indoor temperature.	WGK.	WLA.	WBB.	WFC.	WMD.	WSE.	WLF.	WCG.	WOH.	WTI.	WFJ.
° F.											
36	6	6	4	......	......	......	......	......	......	......	......
33	8	8	8	......	......	......	......	......	2	......	......
30	13	14	16	5	......	......	......	......	3	......	2
27	16	16	18	3	......	......	......	......	4	......	3
24	15	16	18	8	1	3	......	......	6	3	2
21	14	13	18	9	1	4	1	......	3	2	6
18	15	14	16	10	3	7	2	1	1	4	2
15	9	7	12	11	4	5	2	1	1	7	1
12	7	6	13	4	4	12	9	2	......	11	0
9	8	4	11	5	5	8	8	3	1	10	1
6	5	3	10	6	7	8	7	3	1	8	1
3	1	1	5	2	3	5	5	2	0	5	0
Total ..	117	108	147	64	28	54	34	12	22	50	27

TABLE 3.—*Total number of occurrences of the various types of window-frost crystals within the several cold, unheated rooms in connection with various indoor humidities.**

Relative humidity indoors.	WGK.	WLA.	WBB.	WFC.	WMD.	WSE.	WLF.	WCG.	WOH.	WTI.	WFJ.
%											
41	......	......	......	......	......	......	......	......	......	......	......
44	......	......	1	......	1	1	1	......	......	1	......
47	......	......	1	1	......	......	......	......	......	......	......
50	2	2	2	1	......	1	1	......	......	1	......
53	4	4	5	5	......	4	1	......	......	3	1
56	14	19	20	8	......	7	2	......	3	5	1
59	16	21	22	9	3	8	3	1	2	6	3
62	17	10	21	10	3	5	3	1	4	4	4
65	14	15	20	7	4	4	3	2	7	4	5
68	4	5	8	4	2	2	1	1	2	3	3
71	4	4	3	......	......	1	1	......	......	2	......
74	9	8	9	3	1	2	2	1	2	1	1
77	7	9	8	4	2	4	3	......	......	3	2
80	6	7	10	4	3	3	3	......	2	4	3
83	4	2	6	5	4	4	4	2	......	5	2
86	4	2	7	1	4	5	3	4	......	6	1
89	1	1	2	1	1	2	2	......	......	1	1
92	0	1	1	1	1	1	1	......	......	1	......
Total...	106	108	147	64	28	54	34	12	22	50	27

*It is to be noted that practically all the frost forms that occurred within atmospheres possessing relative humidity of over 71 per cent formed only within the coldest room in which the running water and open water tank were situated. It should be further noted that practically all the frost forms that occurred wherever the indoor temperature was above 24° F. formed within the two warmer rooms.

WFJ failed to form upon the windowpanes within the least humid room. We may conclude from this that they form only under relatively high degrees of humidity. Frost formed in some instances within the two warmer rooms when the temperature indoors stood at 36° F. and outdoors at 30° and 28° F.; but in only one instance did frost form upon the windowpanes within the coldest room until the indoor temperature had fallen to at least 24° F. The several types of frost possessing close, solid forms, which we have termed types WTI, WLF, WSE, form only when the indoor temperature stands at 24° F. or below and the outdoor at 15° or below. Their occurrence at a given temperature, however, depends somewhat upon humidity, for they formed upon the windowpanes within the driest and least humid of the several rooms only when the indoor temperature stood at 20° F. or below and the outdoor at 15° F. or below. The student who wishes to pursue further the matter relating to the occurrence of the various types under diverse conditions may find much of interest in the appended Tables 1, 2, 3.

(29) Repulsion between crystals and liquid particles.

One of the most singular, and doubtless most important, phenomena that occur in connection with the formation of window frost is this: The true crystalline varieties of window frost ordinarily, apparently, repel the minute liquid particles or droplets of water that frequently collect like tiny dewdrops on the glass, and freeze in granular form thereon. (See window frost, type WGK, section 41.) This phenomenon is endowed with the greatest interest, because the repulsion operates also within the clouds while snow crystals are in process of formation, and hence has an important bearing on forms and structure of snow crystals, and in keeping them free from granular deposits of a like nature. If, as is presumably the case, snow crystals, under ordinary conditions of humidity, also naturally repel the liquid cloud or mist particles that surround them while within the clouds, this offers a true and complete explanation of why these particles so frequently escape colliding with crystals, and are prevented from attaching themselves in granular form to true snow crystals while the latter are falling thru the clouds. It is quite possible that were it not for this repellent phenomenon, enacted within the clouds among the snow crystals, clear, transparent, and beautiful snow crystals would rarely, or never, occur in nature, and fall to earth.

We can only conjecture as to the cause of this most interesting phenomenon. It may be of an electrical nature. Possibly both the snow and frost, and the liquid cloud or dew droplets, possess an excess of the same kind of electricity, positive or negative. If so they would naturally repel each other. Much discussion has arisen from the fact that window-frost and window-ice crystals within rooms heated artificially form first and in greater quantity upon the lower portions of the windowpanes. That they do so is owing largely, if not wholly, to the fact that cold, outside air enters at the top of each window and where the two sashes meet, and being so much heavier than the warm, indoor air, flows downward, and laves the greater part of the upper portion of such windowpanes. The same thing will happen, tho to a lesser extent, as regards the sides of the panes, if an aperture be made for the outside air to enter in such a way as to lead it out over the surface of the glass. That outside air enters at the top of such sashes during the winter time, and flows downward, may be proved by holding a smoking stick close to the top of each window sash and observing how the smoke is driven downward by such inflowing and descending cold, outdoor air. The explanation of the phenomenon of the deposition of window frost and dew in greater quantity upon the lower than upon the upper portions of the windowpanes lies largely in this fact, that the cold, heavy, outdoor air that enters at the top of each window sash and flows downward over its upper portions, is usually relatively much drier than is the indoor air, and hence not in condition, when it first enters, to deposit any of its moisture upon the glass in the form of frost or dew. But as it flows downward toward the bottoms of the panes, it mixes more and more with the warm, moist air that it meets on its downward journey, and tends to chill it, and hence to bring the latter into a condition of supersaturation for its temperature whereby it must deposit some of its moisture upon the windowpanes, in the form of frost or dew. This phenomenon occurs but feebly, or not at all, as regards the frost and dew that collects upon the windowpanes within cold, unheated rooms.

IV.—CLASSIFICATION OF WINDOW-FROST CRYSTALS.

(30) List of types.

The numerous varieties or types of window frost that recur so often and in such characteristic forms seem to be entitled to receive separate mention as distinct types. Each has been given a distinguishing name, as below, because of certain peculiarities of form or of resemblance to the forms of certain objects in nature. Their place in the following list accords as nearly as practicable with the relative frequency of their respective occurrence both within cold, unheated, and warm, heated rooms.

Type WLA.	Linear crystals; resembling serrated lines.
Type WBB.	"Branch like"; resembling trees, ferns, etc.
Type WFC.	"Filamentous"; resembling sea moss, etc.
Type WMD.	"Meandering", tufted forms.
Type WSE.	"Stelliform"; resembling stars.
Type WLF.	Solid "lamellar" crystals.
Type WCG.	"Columnar"; resembling columns.
Type WOH.	"Open", wrench-like forms.
Type WTI.	"Tooth-shaped" crystals.
Type WFJ.	"Fibroid" forms; resembling fibers.
Type WGK.	"Granular" frozen dew frost.

Each of these several types will, in accordance with our scheme of treatment, receive separate mention in the following sections.

(31) Type WLA. Linear crystals.

This very common type of window frost occurs upon window glass in the form of long, slender, serrated thread-like crystals. Large numbers of such crystals often cross and recross one another upon the glass and thus form delicate lace-like designs thereon. Linear crystals grow both in straight and in curving fashion, but most commonly pursue nearly straight paths. They commonly if not invariably form within minute natural striations within the glass, but will also often form within those made artificially, and hence may be made to follow and to elaborate artificial designs that may be scratched on the glass. They consist of a nuclear or quill portion lying wholly within the striation or scratch in the glass, and of an outlying serrated portion, consisting of myriads of tiny and usually very short secondary rays or branches shooting outward at various nearly perpendicular angles from the nuclear quill. They freely form both within cold and within heated rooms, and under varying degrees of cold and humidity, and form freely in a very humid atmosphere. They often grow very rapidly under humid conditions, threading large glass areas in a very short time. They are most common to heated rooms, and are often found forming and growing upon the same pane of glass in association with granular window frost, type WGK. When cold, moist rooms are slowly warmed in winter these two types often form and replace each other in alternate order upon the glass. Usually tiny serrated frost crystals appear first upon the lower portions of the windowpanes; but as the warmth and humidity within the room increase dew-like deposits form around the linear crystals and extend somewhat above the portions of the lower part of the pane whereon the linear crystals formed. This dew-like deposit immediately freezes upon the glass in granular form and covers all the dry glass spaces lying around, but not close to, the linear crystals. The deposition of this dew-like deposit momentarily reduces the humidity of the air near the windowpane, and as a result linear frost crystals again form on the dry, unoccupied glass spaces lying just above the limits of the dew-like granular film. This alternate process of the formation of frost and then of dew deposits upon the windowpanes is repeated time and again until the windowpanes may be entirely covered by such mixt deposits. Whenever the humidity momentarily exceeds a certain point dew-like deposits collect upon the glass, and whenever it is momentarily reduced below a certain point frost deposits collect. The subsequent melting of this thin film of frost and frozen dew forms the thin films of water that so often cover windowpanes in winter and within which the beautiful feathery window-ice crystals form. (See window-ice crystals, section 45.)

Typical examples of linear frost crystals are shown in our photographs Nos. 29, 100, 107, and 126. It is to be noted that the remaining numbers of our series showing this type of crystals, Nos. 25, 44, 45, 108, 185, 186, 187, 192, and 193, contain other types of crystals, or sections of granular film, type WGK, in addition to the linear crystals under consideration. Linear window-frost crystals often develop in the form of various fanciful figures. No. 100, for instance, has a close and remarkable resemblance to telegraph poles and lines, while No. 108 outlines a beautiful and delicate cross.

Nos. 185, 186, 187, and 193 formed slowly within a cold room. They exhibit the handiwork of the frost in imitating the letters of the alphabet, and in following and elaborating artificial designs scratched with carborundum upon a windowpane. The writer scratched his initials upon a windowpane, and a curved line above, and each winter, from time to time, linear frost crystals form within those scratches and evolve beautiful and artistic letters resembling those shown in Nos. 185, 186, 187, 192 and 193. Nos. 185 and 193 show this formation in its first or skeleton stage. Nos. 186 and 187 were taken at a second stage and portray the decorative efforts of the frost, in still further elaborating and adding to the original skeleton design.

(32) Type WBB. Branching window frost.

Window-frost crystals of this type possess open, branching tree, fern, or star-like forms. They vary greatly one from another in size, the number and arrangement of both primary and secondary rays, etc. Hardly two form and grow to be just alike in every particular.

They possess from one to six or eight primary or quill rays, and in many cases myriads of secondary ones. The secondary rays, in general, project at angles of about 60° from the primary quill rays, yet in many cases they deviate from this rule and grow outward at perpendicular and various other angles. In general, both primary and secondary rays grow in straight or but slightly curving fashion, and both are usually of a somewhat thick and substantial character. They are essentially fast-growing types of window frost. This type of crystal is common to both warm and cold rooms and to various temperatures, etc., but is most common to cold, unheated rooms and indoor temperatures ranging from 32° to 5° F., and humidity 55 to 70 per cent. It furnishes many of the most beautiful window-frost designs, and countless windowpanes in winter are beautified by it. This, as well as all other types of window frost and window ice, gleams and glistens in a most beautiful manner upon the windowpanes; but of course this is all lost in the photograph. Only those who have seen frosted windowpanes lit up by a bright winter moon, or seen them flash and sparkle under the rays of a winter sun, have seen the full beauty of the frost.

There is little room for doubt that were it not for minute inequalities in the thickness and the surface of the window glass on which they form, this type of window-frost crystal would often develop in a perfectly symmetrical hexagonal manner, in six-pointed star-like forms that would rival in beauty certain branching forms of snow crystals, which closely resemble them. (See Nos. 21, 95, 119 A, 119 B, and 128.) We have secured a large number of photographs of this elegant type of window-frost crystals, among which will be found many of the choicest and most beautiful designs.

The series of photographs of such is as follows:

Nos. 3, 4, 5, 10, 21, 22, 23, 40, 42, 43, 48, 54, 55, 56, 60, 64, 65, 66 B, 67, 69, 70, 77, 85, 95, 102, 103, 104, 105, 106, 109, 112, 119 A, 119 B, 122, 123, 124, 125, 128, 143, 144, 145 A, 145 B, 166, 167, 194, 202, 203, 204, 205, 219, 220, 222, 226, 227 A, 227 B, 227 C. Many of these, particularly Nos. 55, 64, 95, 102, 124, 194, 220, are exquisitely beautiful. No. 70 contains two crystals resembling spiders or crabs, which are so similar to each other as to deserve the title, "twins". Many of the individual crystals of this type grow and develop in the semblance of various fanciful designs, or so as to resemble certain natural objects.

No. 85 might well pass for a tapestry design; No. 102 for a sprig of fern; Nos. 119 B, 21, and 95 for snow crystals; Nos. 123, 124, and 167 for maple leaves; Nos. 145 A and 145 B for tiny trees wrought in crystal. The letter **Y** design in No. 144, and the scorpion design in No. 125 are also curious examples of the seemingly imitative work of the frost. Nos. 109 and 143 show typical frost formation occurring around ice and small icy particles frozen on a windowpane.

Sometimes the individual crystals of this type assume curving, spiral forms, and Nos. 54 and 102 are very interesting examples of such. The beautiful photograph, No. 220, shows a most elaborate design, evidently wrought out around a simple spider or crab-shaped nucleus, originally similar to No. 70. In No. 226 we see a fine example of triangular development. This type of window frost has many points of resemblance to the feather forms of window-ice crystals, and doubtless corresponds, type for type, with them. They thus have their prototypes both among the snow and the ice crystals. We shall include under this head a somewhat composite type of window frost.

These exquisite forms of frost possess somewhat meandering habits of growth, and in this regard resemble the type next to be described, type WFC, but unlike that they grow in a broad substantial manner, more like type WBB. In many cases their rays are even broader and more substantial than are the rays of type WBB. Crystals of this character form and grow outward from a common nucleus, in rosette-like forms, as shown in No. 227 B, or from granular frost, or other types of frost, in leaf or coral-like shapes as shown in No. 227 C.

(33) Type WFC. Filamentous type.

These extremely delicate and graceful frost crystals consist of a vast number of separate curving filaments of frost radiating outward, or in some general direction from a common center, or from such other window-frost crystals as they may form around, which serve as their nuclei. The slender delicate filaments of which they are composed almost invariably pursue sinuous, meandering, rather than straight or gently curving paths on the glass. They form almost exclusively upon windowpanes within cold rooms, and are most common to indoor temperatures ranging from 28° to 6° F., and humidities of 55° to 65 per cent and are often found associated thereon with various other types of window frost, but particularly with type WBB.

The mystery of why the ice filaments, of which it is composed, grow in such a sinuous and seemingly uncrystalline manner is as great as it is in the case of the corresponding meandering arborescent type of window-ice crystal, type IAB. Certain temperatures and humidities evidently favor its formation, because sometimes and in certain cases window-frost crystals, especially of type WBB, cease to grow and are succeeded by type WFC. In many cases the latter type adopts the former as a nucleus and grows outward therefrom.

We have selected 18 examples of this most elegant type of window-frost crystal for use as illustrations, as follows: Nos. 30, 31, 42, 69, 73, 115, 117, 130, 131, 132, 146, 147, 148, 177, 179, 195, 196 A, 196 B. Nos. 130, 131, and 196 A are particularly lovely and interesting examples. As will be noted, some of them resemble sea moss. Tiny crystals of type WBB form the nuclei of specimens Nos. 130, 131, 132, and 195.

Sometimes a very slight change (increase) in the indoor humidity, accompanied by a fall of but a few degrees in outdoor temperature, will cause crystals of this type to form and grow between or around crystals of type WBB, as shown in the very interesting photograph No. 196 B.

(34) Type WMD. Meandering window frost.

These singular frost crystals consist in some cases of but a single straight or curving spike or quill, and in others of a central quill adorned with a few or with many secondary tuft-like branches. Such tuft-like secondary branches as may form upon and around the primary quill or spike usually appear clustered together into tufts thereon. Singularly enough many of the secondary branches grow outward from the central quill perpendicularly rather than at an angle of 60°.

These odd crystals are essentially very cold weather types and form only within cold, unheated rooms during below-zero weather. They form freely only when the indoor temperatures range from 15° F. downward. They form freely in a very cold atmosphere, when the relative humidity of the air ranges from 77 to 86 per cent, and less freely within warmer air at humidities of from 55 to 65 per cent. Sometimes the longer varieties of this type of crystal seem to possess a structure nearly continuous, as in Nos. 175, 176, and 178, while in other cases they seem to be built outwardly in sections, as in Nos. 58 A, 58 B, 59, 154 A, 154 B, and 188.

(35) Type WSE. Stelliform crystals.

Crystals of this type are of a somewhat close structure. In many cases a simple hexagonal star forms the nucleus, the rays of which terminate in tiny solid hexagonal plates.

They commonly form around and upon tiny bits of ice, or tiny frost crystals, and usually develop parallel to, but slightly raised from, the window glass, except when their nucleus is itself attached to the glass. They evidently grow outward in intermittent, rather than continuous, order, whenever the temperature suddenly falls, or a windowpane is suddenly cooled far below its previous temperature, as the result of a cold gust of wind suddenly springing up and striking it. They are slow-growing, cold weather types, and occur only in cold rooms and during below-zero weather. Indoor temperatures must be as low as 20° F. for them to form freely. They form most freely within cold rooms at humidities ranging from 74 to 90 per cent, less freely at milder temperatures, when the relative humidity ranges from 55 to 65 per cent.

They usually fail to attain perfectly symmetrical proportions, for the reason that they commonly form in such a position that their growth does not progress equally in all directions. In rare instances their position and environment is such as to allow development to proceed in all directions, and in such cases they assume quite symmetrical forms. See Nos. 161 and 154 B (it is to be noted that one point of No. 161 is broken partly off).

Crystals of this same general character sometimes form around, or develop annex-fashion from, other frost types. No. 145 A is a very beautiful and unique example, in which the stelliform crystal formed around and grew outward as an annex to the branching type of window frost, type WBB.

It is to be noted that this type of frost, altho for convenience grouped under the title "Window frost", develops largely outward from, and independent of, the surface of the glass, and hence is in reality a type of indoor hoarfrost. (See type HTF, tabular hoarfrost, section 16.)

[*To be continued.*]

INTERNATIONAL METEOROLOGY.

The following is an extract from an address by Prof. Arthur Schuster, of Manchester, delivered before the Royal Institution of Great Britain Friday, May 18, 1906, and is reprinted from Nature and from the Annual Report of the Smithsonian Institution for 1906:

In an address delivered to the British Association at its Belfast meeting, in 1902, I expressed the opinion that meteorology might be advanced more rapidly if all routine observations were stopped for a period of five years, the energy of observers being concentrated on the discussion of the results already obtained. I am glad to say that meteorologists have taken seriously a remark the echoes of which still reach me from distant parts of the earth. They disagree with me, but their disagreement is of the apologetic kind. I do not wish to retract or to weaken my previous statement, but merely now qualify it to the extent that it is only to be applied to two-dimensional meteorology. There is a three-dimensional meteorology as far removed from the one that confines itself to the surface of the earth as three-dimensional space is from a flat area. Three-dimensional meteorology is a new science, which at present requires the establishment of new facts before their discussion can properly begin. The extension of our range of observations by kites and balloons is of comparatively recent origin. Mr. Archibald in this country was one of the pioneers of meteorological investigation by means of instruments attached to kites. In the United States Mr. Rotch, having established a separate observatory, succeeded in convincing scientific men of the great value of the results which could be obtained. Mr. L. Teisserenc de Bort, who established and maintained an observatory for dynamic meteorology at Trappes, near Paris, rendered similar services with regard to "pilot" or unmanned balloons carrying autographical instruments. The aeronautical department of the Royal Prussian Meteorological Institute, with Doctor Assmann at its head, under the direction of Professor von Bezold, also made a number of important contributions in the early stages of the work. Professor Hergesell, of Strasburg, similarly made numerous experiments; and chiefly through the efforts of those whose names have been mentioned, and more especially Professor Hergesell, an international agreement has been secured by means of which kite and balloon ascents are made in several countries on the first Thursday in each month and on three consecutive days during two months of the year. A large station for aeronautical work was recently established at Lindenburg, near Berlin, where kites or balloons are sent up daily for the purpose of securing meteorological records. The greatest height yet reached was during the ascent of the 25th of November, 1905, when by means of several kites sent one after another on the same wire the upper one rose to an altitude of 6430 meters, almost exactly four miles. Owing to want of funds this country could until recently only participate in this work through the individual efforts of Mr. Dines, who received, however, some assistance from the British Association and the Royal Meteorological Society.

The reconstruction of the meteorological office has made it possible now for Mr. Dines's work to be continued as part of the regular work of that office, and further stations are being established. Mr. Cave carries out regular ascents at his own expense at Ditcham Park, and through the cooperation of the